INVESTIGATIONS ON BIOACTIVE GLASS AND GLASS-CERAMICS FOR BIOMEDICAL APPLICATIONS

ABSTRACT

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Bioactive glasses, a group of biomaterials, are capable of forming a hydroxycarbonate apatite (HCA) layer on their surface when in contact with physiological solution after the series of surface chemical reactions. The obtained HCA layer has composition and structure similar to the mineral phase of the bone and it forms strong bonding at the interface of bioactive glass implants and tissues. Thus, these aspects make bioactive glasses different from other biomaterials and make it a potential candidate for the various applications in tissue engineering. By tuning the chemical compositions of these glasses, rates of HCA formation and bonding to different tissues can be controlled. The formation a HCA layer on the bioactive glass surface is usually taken as an indication of bioactivity of the glass in vivo conditions. After the discovery of first bioactive glass such as 45S5 by Prof. Hench and his co-workers, this type of glass has been investigated extensively both in vitro and in vivo conditions. However, the compositional limits and the physicochemical and biological properties of these glasses are not fully understood.

The formation of HCA layer in bioactive glass is ascribed to the series of surface reactions, which has been proposed by Prof. Hench, since then it is called as Hench Mechanism (HM). It has been observed through the HM that bioactive glasses develop HCA layer and bond to the bone via series of surface reactions, i.e. ion exchange between the surface and the surrounding medium. Numerous experimental investigations has confirmed that the presence of silanol groups on surface acts as nucleating sites for the HCA layer formation. Additionally, it has been revealed that several other factors controls the HCA layer formation, more importantly the textural factors, i.e. surface area, pore size, and pore volume. Following this, the research has been focused on the development of bioactive glasses with ordered/disordered mesoporous structure, which shows the enhanced in-vitro bioactivity than the corresponding melt derived bioactive glasses. The mesoporous bioactive glasses have shown to be exceptional candidates for different biomedical applications such as local drug delivery systems and bone tissue regeneration.

The presence of high surface area and significant pore volume in bioactive glasses greatly accelerates the HCA formation and therefore enrichment in the bone bonding character. Moreover, these materials can be loaded with osteogenic agents promoting new bone formation in vivo and it can be applied as scaffolds for bone tissue engineering. Apart from highly ordered mesoporous materials the other kind of less

ordered wormhole-like mesoporous materials has been developed recently. Although less ordered wormhole-like mesoporous materials lack regular channel packing order, but exhibit uniform channel diameter and short range hexagonal like packing order. Furthermore, under certain circumstances wormhole-like channels are giving better performance by facilitating the access of the molecules to the reactive sites present inside the channels and hence offering good opportunity in catalysis, adsorption, separation and immobilization

The present thesis work is broadly classified into two parts. The first part deals with the ion transport mechanism in melt-derived bioactive and bioinert soda-lime phosphosilicate glasses. A new insight into strong links between ion transport mechanism and local structure has been obtained in these glasses. These correlations have been obtained by using the high temperature Raman spectroscopy and nuclear magnetic resonance (NMR) spectroscopy. The local structural changes in silicate and phosphate species play crucial role in ion transport process. An understanding of ion transport in these glasses is an important aspect, since the influence of surface charge on the HCA formation was confirmed by the overgrowth of CaP layers in the SBF, by the proliferation of certain cells in physiological fluids, and by an enhanced osteoconductivity in the body. The release of alkali and alkaline-earth ions is the key factor for effective integration of the implants through interfacial bonding. Additionally, this new information in silicate glasses containing alkali-alkali-earth ions would enrich the understanding the ion transport behaviour of magnetic system.

The second part of thesis deals with the synthesis, characterization, and in vitro bioactivity studies of various mesoporous sol-gel prepared silicate glass compositions. We have studied binary, ternary, and quaternary glass compositions with alkali oxide content by tuning the network modifier/former ratios. In particularly, the quaternary glass compositions are close to 45S5 bioglass and show the enhanced HCA formation with an estimated Ca/P ratio is close to hydroxycarbonate. Additionally, we have also investigated and compared the structure and bioactivity of sol-gel derived mesoporous glasses and glass-ceramics in quaternary system with constant alkali and by varying alkaline-earth oxide content. We observed that textural properties such as high surface area, pore size, and pore volume is related to high density of silanols (Si-OH) and account for bioactivity in these mesoporous glasses.